The impact of LEP 2 data on possible anomalous enhancements of $Re \ \epsilon'/\epsilon$

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Abstract

It has been shown in the past that the real part of the ϵ'/ϵ ratio is particularly sensitive to anomalous gauge couplings that modify the Standard Model Lagrangian. Due to the loose bounds on these couplings coming from low energy processes and to the poor sensitivity of hadron colliders to couplings such as Δg_1^Z , it has been argued that anomalous couplings could still produce an enhancement of $Re \ \epsilon'/\epsilon$ bringing this observable closer to the experimental value obtained by KTeV, NA31 and NA48. The impact of the new measurements done at LEP 2 in these years is discussed and new severe constraints to this hypothesis are determined.

Since 1995, it has been noted [1] that anomalous triple gauge couplings (TGC) involving $WW\gamma$ and WWZ vertices could modify significantly the Standard Model (SM) prediction concerning ϵ'/ϵ . More precisely, strong penguin diagrams and isospin breaking due to quark masses completely dominate the SM prediction of $Re\ \epsilon'/\epsilon$ for low values of m_t . However, for m_t of the order of 170 GeV, the effects of electroweak penguin diagrams are sizeable [2] and therefore $Re\ \epsilon'/\epsilon$ becomes sensitive to anomalies in the bosonic sector of the SM.

The possibility that anomalous TGC could modify and, particularly, enhance $Re \ \epsilon'/\epsilon$ has been considered with interest, especially because several experimental measurements still point towards a rather high value of $Re \ \epsilon'/\epsilon$ with respect to the SM expectation. In fact, present theoretical errors on $Re \ \epsilon'/\epsilon$, coming mainly from the uncertainties in the models for hadronic matrix elements, prevent us from drawing conclusions about the effectiveness of SM in the CP violating sector. On the other hand, it is interesting to quantify to what extent the hypothesis of anomalous enhancement of $Re \ \epsilon'/\epsilon$ is corroborated by the intense experimental investigation on the bosonic sector of the SM carried out at LEP 2 since 1996.

It is customary to express general deviations from the SM in the bosonic sector in the framework of effective theories [3]. In this case, the most general Lagrangian invariant under $U_{em}(1)$ that contributes to WWV vertices $(V = Z, \gamma)$ [4,5] is:

$$i\mathcal{L}_{eff}^{WWV} = g_{WWV} \cdot \left[g_{1}^{V} V^{\mu} (W_{\mu\nu}^{-} W^{+\nu} - W_{\mu\nu}^{+} W^{-\nu}) + \kappa_{V} W_{\mu}^{+} W_{\nu}^{-} V^{\mu\nu} + \frac{\lambda_{V}}{M_{W}^{2}} V^{\mu\nu} W_{\nu}^{+\rho} W_{\rho\nu}^{-} + i g_{5}^{V} \varepsilon_{\mu\nu\rho\sigma} ((\partial^{\rho} W^{-\mu}) W^{+\nu} - W^{-\mu} (\partial^{\rho} W^{+\nu})) V^{\sigma} + i g_{4}^{V} W_{\mu}^{-} W_{\nu}^{+} (\partial^{\mu} V^{\nu} + \partial^{\nu} V^{\mu}) - \frac{\tilde{\kappa}_{V}}{2} W_{\mu}^{-} W_{\nu}^{+} \varepsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} - \frac{\tilde{\lambda}_{V}}{2M_{W}^{2}} W_{\rho\mu}^{-} W_{\nu}^{+\mu} \varepsilon^{\nu\rho\alpha\beta} V_{\alpha\beta} \right] ,$$

$$(1)$$

where $W^{\pm\mu}$ are the W boson fields and $V=\gamma,Z$. Defining $g_{WW\gamma}=e$ and $g_{WWZ}=e$ $\cot\theta_W$, this Lagrangian allows anomalous values for the C- and P-conserving couplings κ_{γ} , κ_{Z} , g_{1}^{Z} , g_{1}^{γ} (equal to 1 in SM). Moreover, new contributions coming from operators absent in the standard theory are present. These are λ_{V} , which also conserves both C and P-parity; g_{5}^{V} (C and P violating but CP conserving) and the CP violating terms g_{4}^{V} , $\tilde{\kappa}_{V}$ and $\tilde{\lambda}_{V}$. In terms of the W magnetic dipole and electric quadrupole they contribute as

$$\mu_W = (g_1^{\gamma} + \kappa_{\gamma} + \lambda_{\gamma}) \frac{e}{2m_W} s ; Q_W = -\frac{e(\kappa_{\gamma} - \lambda_{\gamma})}{m_W^2} , \qquad (2)$$

where eg_{γ}^1 is the W charge and s its spin. To simplify the notations, it is convenient to introduce the deviation from the SM couplings

$$\Delta g_1^V \equiv g_1^V - 1$$
 , $\Delta \kappa_V \equiv \kappa_V - 1$.

CP-violating terms are constrained by the neutron and electron electric dipole moments [6]. CP-conserving anomalous couplings affect low-energy rare decays [7], W production processes at high scales (LEP 2 and Tevatron) and electroweak corrections to the W,Z,γ propagator ("oblique corrections"). Oblique corrections have been extensively tested at the scale of m_Z at LEP 1 and SLC. In order to evade the tight constraints already obtained from LEP at the Z^0 -pole, present LEP 2 measurements are expressed as limits to couplings contributing to the effective Lagrangian (1) after imposing $SU(2) \otimes U(1)$ gauge invariance and retaining only the lowest dimension operators [8–10]. This approach implies relations amongst the various TGC [10] and reduce the number of independent couplings to three: Δg_1^Z , λ_{γ} and $\Delta \kappa_{\gamma}$.

The CP-violating $\Delta S=1$ interaction responsible for $K\to\pi\pi$ is affected, beyond strong penguins, by electroweak penguins and (possibly) TGC contributions changing both the I=0 and I=2 amplitude. At the scale of $\mu=m_W$, the SM effective Hamiltonian (H_{eff}) for $\Delta S=1$, modified in order to cope with anomalous TGC, has been computed in [11]. It has been shown that the CP-violating couplings and $\Delta\kappa_Z$ do not contribute to leading order, being suppressed by factors of $O((m_{d,s}^2,m_K^2)/m_W^2)$. Running H_{eff} at the scale of $\mu=1$ GeV implies the knowledge of the boundary conditions of the Wilson coefficients in SM [12] and in the occurrence of anomalous couplings [11]. In the calculation of [11] a cut-off Λ of 1 TeV has been used for terms proportional to Δg_1^Z and $\Delta\kappa_\gamma$. The results obtained in [11] depend, in general, on the anomalous couplings Δg_1^Z , $\Delta\kappa_\gamma$, λ_γ and g_5^Z , on the imaginary part of $V_{td}V_{ts}^*$ and on the assumptions about the hadronic matrix elements.

The dependence of $Re \epsilon'/\epsilon$ to anomalous TGC can be expressed in the following way:

$$Re\left(\frac{\epsilon'}{\epsilon}\right) \simeq \mathcal{H} Im(V_{td}V_{ts}^*) \left(1 + 0.96\Delta\kappa_{\gamma} + 0.16\lambda_{\gamma} - 4.08\Delta g_1^Z + 0.44g_5^Z\right).$$
 (3)

where the overall normalisation factor \mathcal{H} depends mainly on the knowledge of the hadronic matrix elements and, according to the calculation of [13], $\mathcal{H} \simeq 8.66$. Due to the clear dominance of the term involving Δg_1^Z , Tevatron results do not modify significantly the low-energy constraints and are not considered here. In the present analysis, we take the current allowed range of $Im(V_{td}V_{ts}^*)$ from [14] and we assume

$$Im(V_{td}V_{ts}^*) = (1.14 \pm 0.11) \cdot 10^{-4}$$
 (4)

It is well known that the status of the experimental measurement of $Re \epsilon'/\epsilon$ is not completely satisfactory. First results were obtained by NA31 [15] and were not confirmed by E731 [16]. Preliminary results from the KTeV [17] collaboration and from NA48 [18] strongly support a non-zero value of $Re \epsilon'/\epsilon$ (fig.1). On the theoretical side, current calculations of

 $Re \ \epsilon'/\epsilon$ in SM point, in general, towards lower values than those suggested by current experiments, even if the statistical significance is of the order of 2-2.5 σ (for a review see [20,14]) and make the hypothesis of an anomalous enhancement of $Re \ \epsilon'/\epsilon$ due to TGC rather attractive. It is interesting to note, however, that some very recent updates of the theoretical calculations of the hadronic matrix elements [14,19] could imply a higher value of $Re \ \epsilon'/\epsilon$ which, if confirmed, would ease the agreement of the SM predictions with the current experimental measurements without invoking new physics. On the other hand, for what concerns TGC the hadronic matrix elements mainly affects the overall normalisation factor $\mathcal H$ being the relative contributions of the couplings (last factor of eq.(3)) practically independent to them. Therefore, the allowed ranges derived in the following assuming $\mathcal H \simeq 8.66$ can be updated in a straightforward manner by proper rescaling of $\mathcal H$ in eq.(3).

Experimental measurements

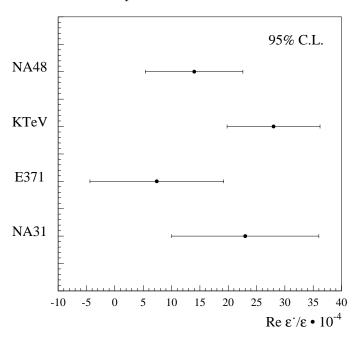


FIG. 1. Present experimental measurements of $Re \epsilon'/\epsilon$ (95% C.L.).

Figure 2 shows the possible enhancement of $Re \ \epsilon'/\epsilon$ as a function of Δg_1^Z , without including current LEP 2 data and assuming all TGC but Δg_1^Z at their SM values. The allowed range of Δg_1^Z has been computed including just the low energy constraints coming from rare B and K decay, as in [11]. The vertical width of the dark band represents the variation of $Re \ \epsilon'/\epsilon$ corresponding to a change of $\pm 2\sigma$ of $Im(V_{td}V_{ts}^*)$. The light band indicates the allowed range from NA31. All the limits are computed at 95% C.L. The plot represents approximately the experimental situation at the beginning of the high energy run of LEP.

Before LEP 2 40 Re $\varepsilon'/\varepsilon \cdot 10^{-4}$ 35 30 25 NA31 20 15 10 95% C.L. 5 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 Δg^{Z}

FIG. 2. $Re~\epsilon'/\epsilon$ as a function of Δg_1^Z for the range of this coupling allowed by low energy data (fixing all the couplings but Δg_1^Z to their SM values). The vertical width of the dark band represents the variation of $Re~\epsilon'/\epsilon$ corresponding to a change of $\pm 2\sigma$ of $Im(V_{td}V_{ts}^*)$. The horizontal extent of the dark band represents the allowed range of Δg_1^Z . The light band indicates the allowed range from NA31. All the limits are computed at 95% C.L.

The current situation is depicted in figure 3. Here the world average has been computed inflating the error until $\chi^2/ndf=1$, in order to deal with the discrepancy between the old E731 measurement and the analyses of KTeV, NA31 and NA48. Simple rejection of E731 results in a world average of (21.6 ± 2.7) \cdot 10^{-4} . The allowed range for Δg_1^Z combines the 95% C.L. limits coming from ALEPH, DELPHI, OPAL and L3 [21] summing up the accumulated statistics from 1996 to 1999 taken at centre-of-mass energies ranging from 161 GeV to 202 GeV. Here, statistical and systematic uncertainties are included.

The remarkable improvement in the experimental tests of anomalous values of Δg_1^Z strongly constraints the hypothesis of anomalous enhancement, bringing the allowed range of $Re \ \epsilon'/\epsilon$ to

$$8.0 \ 10^{-4} < Re \ \epsilon'/\epsilon < 13.7 \ 10^{-4} \quad (95\% \ C.L.) \ ,$$
 (5)

to be compared with the pre-LEP 2 measurement of

$$5.4 \ 10^{-4} < Re \ \epsilon'/\epsilon < 30.5 \ 10^{-4} \quad (95\% \ C.L.) \ .$$
 (6)

Current data (LEP included)

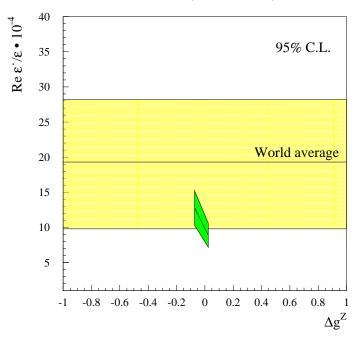


FIG. 3. $Re \ \epsilon'/\epsilon$ as a function of Δg_1^Z for the range of this coupling allowed by low energy and LEP data (fixing all the couplings but Δg_1^Z to their SM values). The vertical width of the dark band represents the variation of $Re \ \epsilon'/\epsilon$ corresponding to a change of $\pm 2\sigma$ of $Im(V_{td}V_{ts}^*)$. The horizontal extent of the dark band represents the allowed range of Δg_1^Z . The light band indicates the current world average of $Re \ \epsilon'/\epsilon$ (see text for details). All the limits are computed at 95% C.L.

These limits have been extracted assuming that only Δg_1^Z is different from zero. In fact, single W production at LEP 2 strongly constraints contributions to the effective Lagrangian coming from operators proportional to $\Delta \kappa_{\gamma}$. The accumulated LEP 2 statistics allows a simultaneous fit of Δg_1^Z and $\Delta \kappa_{\gamma}$ (again, all other couplings have been fixed to their SM value). The corresponding allowed range for $Re \epsilon'/\epsilon$ is

$$7.9 \ 10^{-4} < Re \ \epsilon'/\epsilon < 15.6 \ 10^{-4} \ 95\% \ C.L.$$
 (7)

Contributions from other couplings have very limited impact on $Re \epsilon'/\epsilon$ by virtue of eq.(3). It has to be noted that results for the TGC parameters have been quoted without use of a form factor Λ , describing the scale at which new physics should become manifest. Inclusion of such a parameter with $\Lambda = 1$ TeV, for sake of consistency with [11], and form factors of the type used, for example, in [22] would increase the limits obtained for $Re \epsilon'/\epsilon$ by no more than 4%.

In conclusion, we have shown that present LEP 2 data highly constrain the hypothesis of a non-standard enhancement of $Re \epsilon'/\epsilon$ coming from anomalies in the bosonic sector of the

SM. In particular, the sensitivity of the process $e^+e^- \to W^+W^-$ to Δg_1^Z allows a reduction of the possible contribution to $Re~\epsilon'/\epsilon$ from this coupling by a factor of about 4.

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